Quantum Well Infrared Photodetectors for Low Background Applications

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Abstract

QWIPs operate by photoexcitation of electrons between ground and first excited state subbands of multi-quantum wells (MQWs) which are artificially fabricated by placing thin layers of two different, high-bandgap semiconductor materials alternately. The bandgap discontinuity of two materials creates quantized subbands in the potential wells associated with conduction bands. The structure parameters are designed so that the photo-excited carriers can escape from the potential wells and be collected as photocurrent. Thus, in principle, QWIP operates very similar to extrinsic bulk photocunductors. Electrons in the subbands of the isolated quantum wells can be visualized as electrons attached to impurity states in bulk photocunductors. As photogenerated electron leaves the active doped quantum well region , it leaves behind a space-charge buildup which impedes another electron from entering the detector from the opposite electrode. For low-background irradiance levels, high resistivity of the active region due to thick barriers could leads to a delay in refilling space-charge buildup. This results in a lower responsitivity at high optical modulation frequencies, similar to dielectric relaxation in bulk photocundoctors. In order to overcome this problem, we have designed new QWIP structure separating active quantum well region and blocking barrier. As shown in the figure xxxx, in MQW structure quantum wells are separated by thin barriers creating a miniband due to large overlap of sublevel wavefunctions. Space-charge buldup quickly refilled by electrons via sequential resonant tunneling from the contact layer (left). Similar to block impurity band detectors, a thick impurity free blocking barrier is placed between the active region and collector contact to suppress dark current of the device.

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BY

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Colleagues

QWIP Team:

- Sarath Gunapala
- John Liu
- David Ting
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- Jason Mumolo

Astronomers:

- James Bock
- Michael Ressler
- Michael Werner

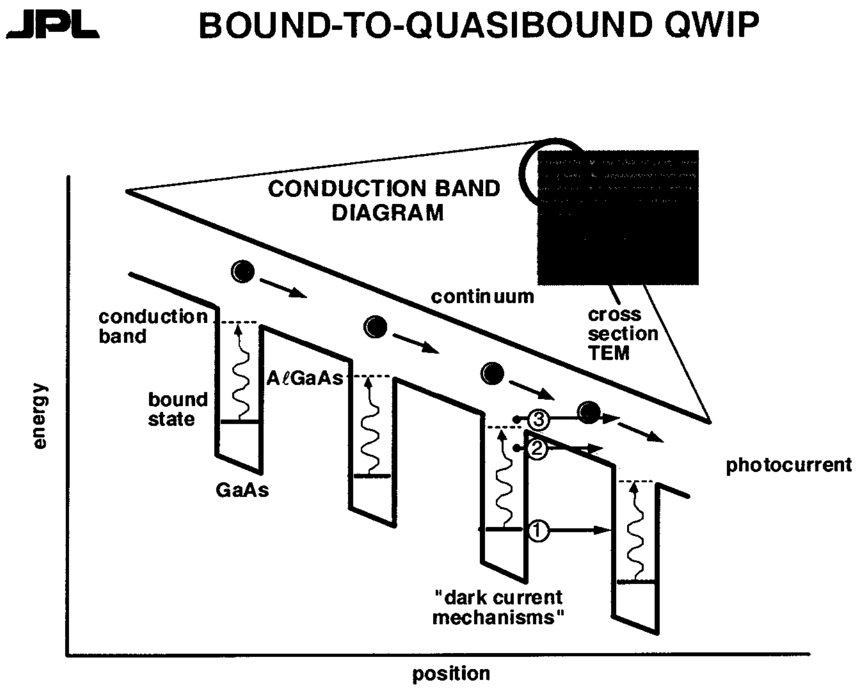
Industrial Partner:

- Indigo Systems

Outline

- Introduction: Typical QWIP Structure
- QWIPs at Low Operating Temperatures
- Non Linear Response in QWIP
- Blocked Intersubband Detector (BID)
- Summary

Typical QWIP



- Bound-to-quasibound structure
- About ~500 A° barriers
- Suppers tunneling current
- At typical operating temperatures (70K for 8.5 μm QWIP), dark current is mainly due to thermal excitation

QWIP Dark Currents at Low Temperature

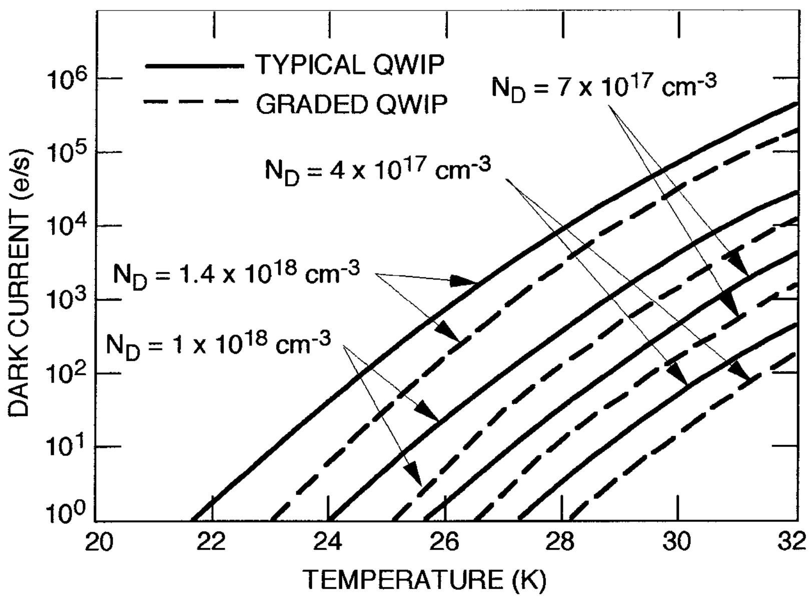


Fig 6

- Estimated dark currents includes
  - Thermal excitation
  - Tunneling
- Cut-off wavelength $\lambda_c = 12\ \mu m$
- Pixel Size: $25x25\ \mu m^2$

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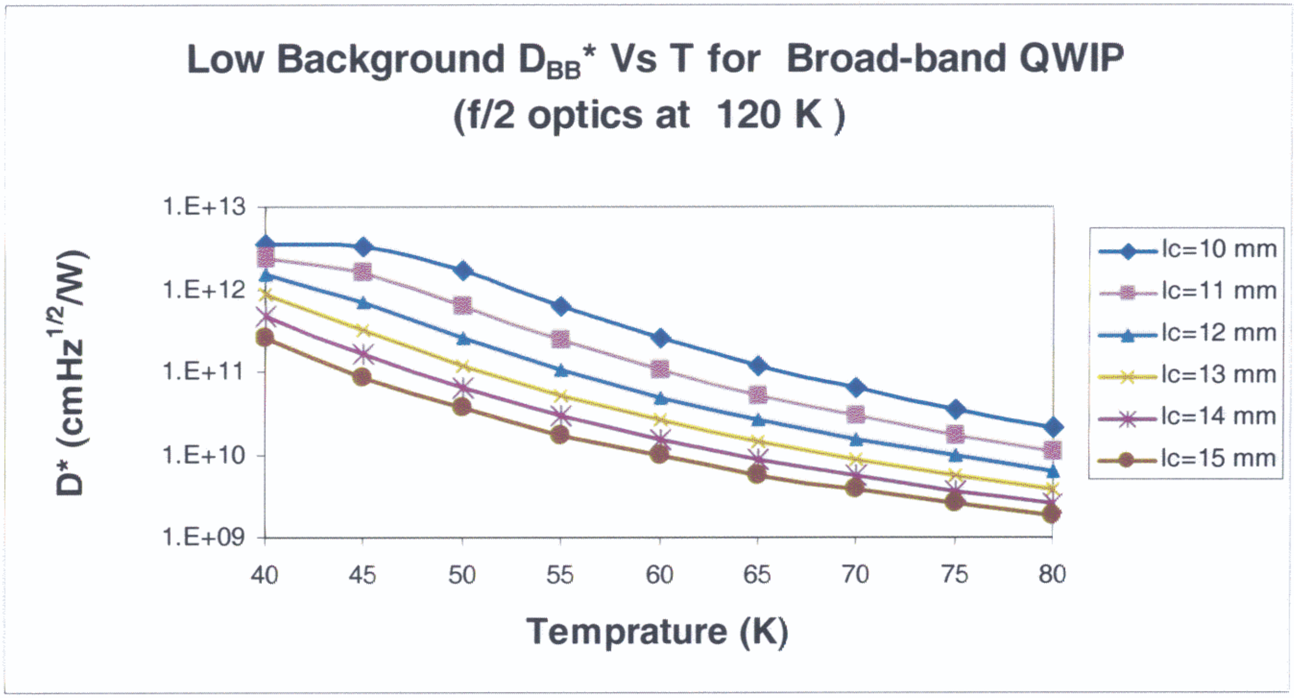
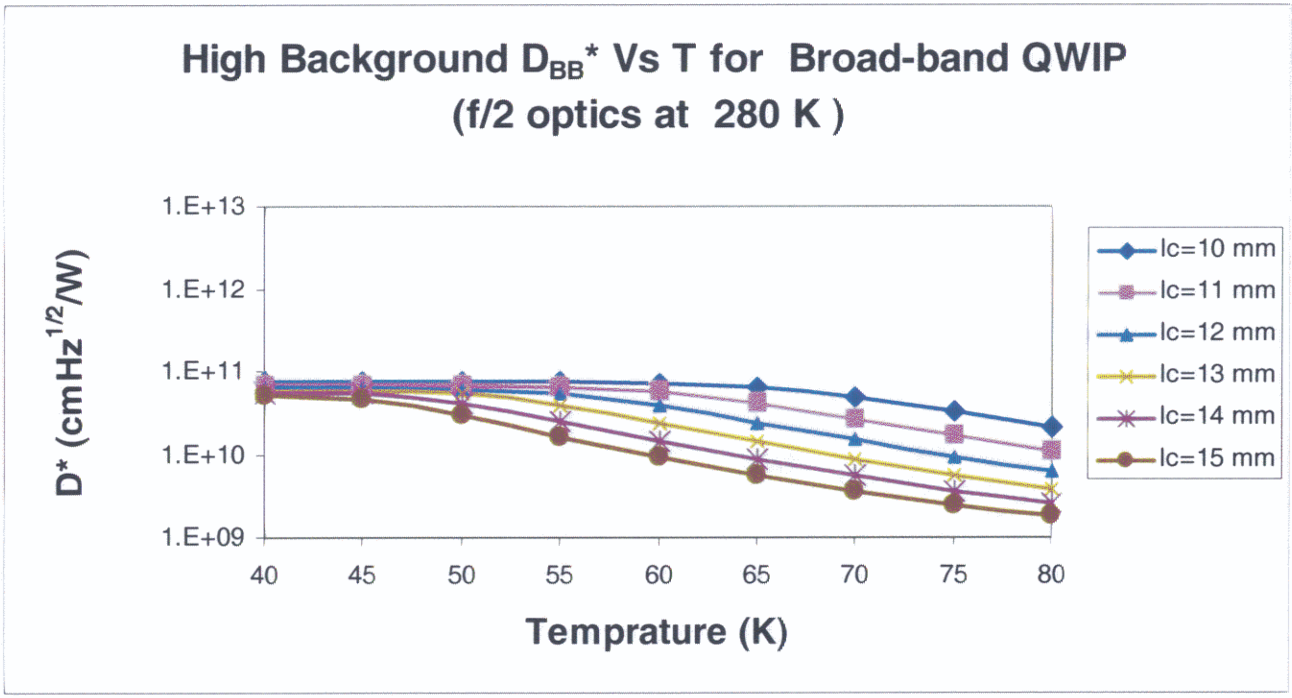
Broad Band QWIP ($\Delta\lambda$ ~ 4 μm) for Low Background Applications
Photon Flux = 1.5×10^{13} ph/sec/cm^2 (120K, f/2)



SVB NEDT7-11.XLS, 6/21/00

Broad Band QWIP ($\Delta\lambda$ ~ 4 μm) for High Background Applications
Photon Flux = 1.3x10^{16} ph/sec/cm^2 (280K, f/2)



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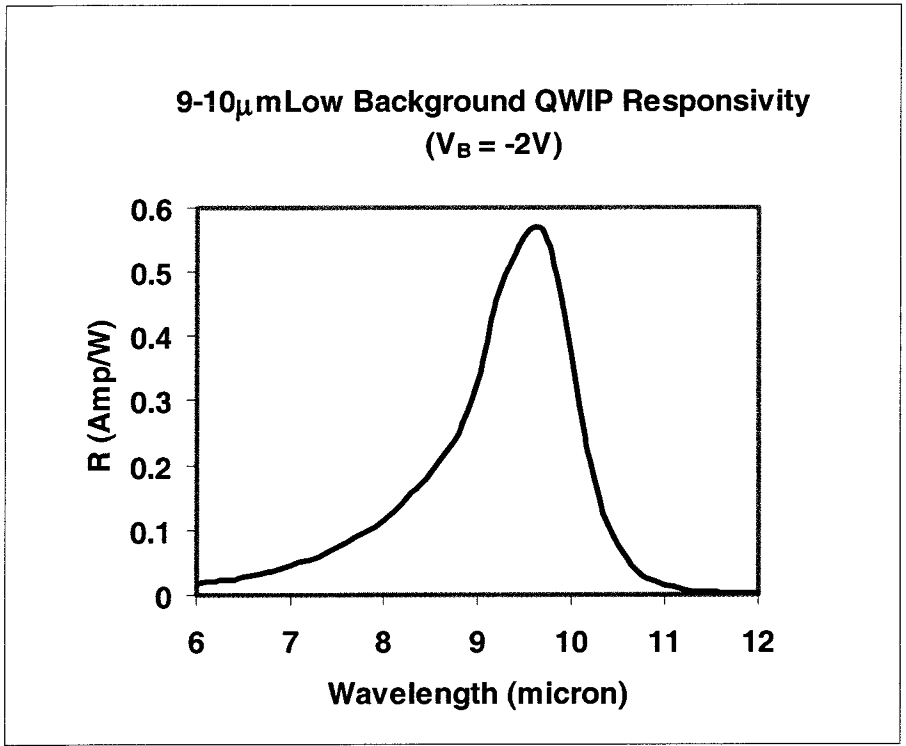
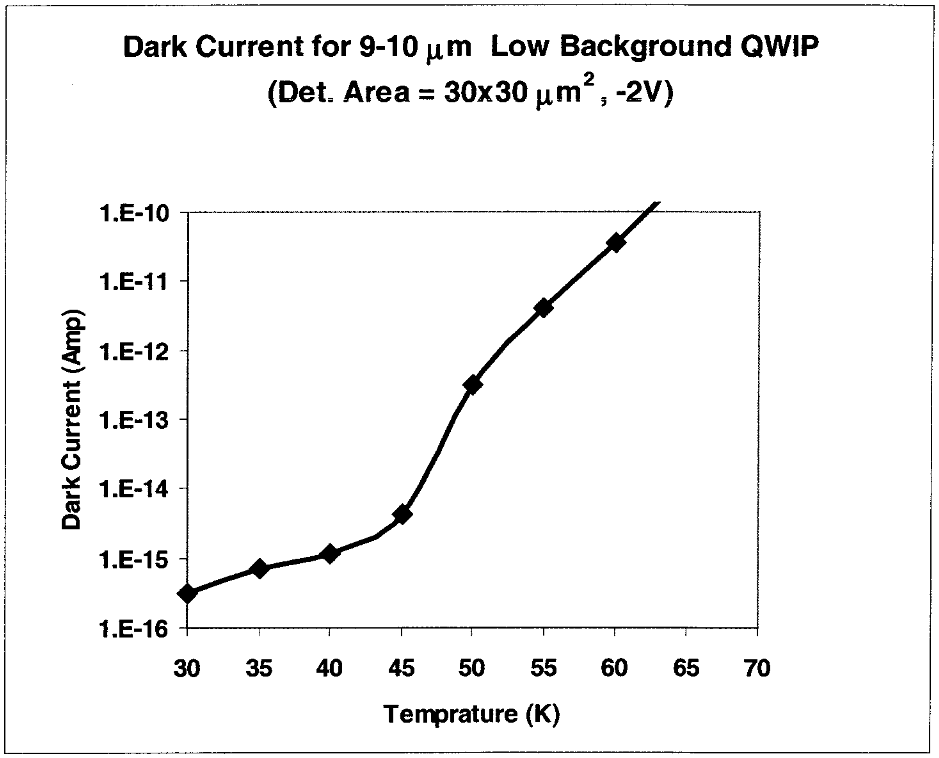
9-10 μm QWIP for Low Background Applications Photon Flux = 1.5×10^{13} ph/sec/cm^2 (120K, f/2)





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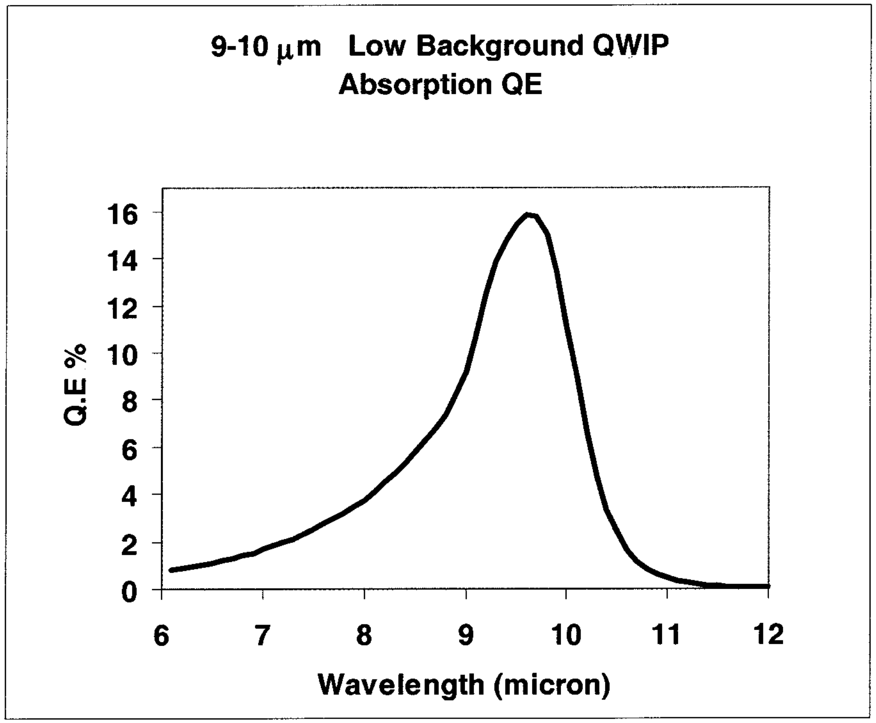
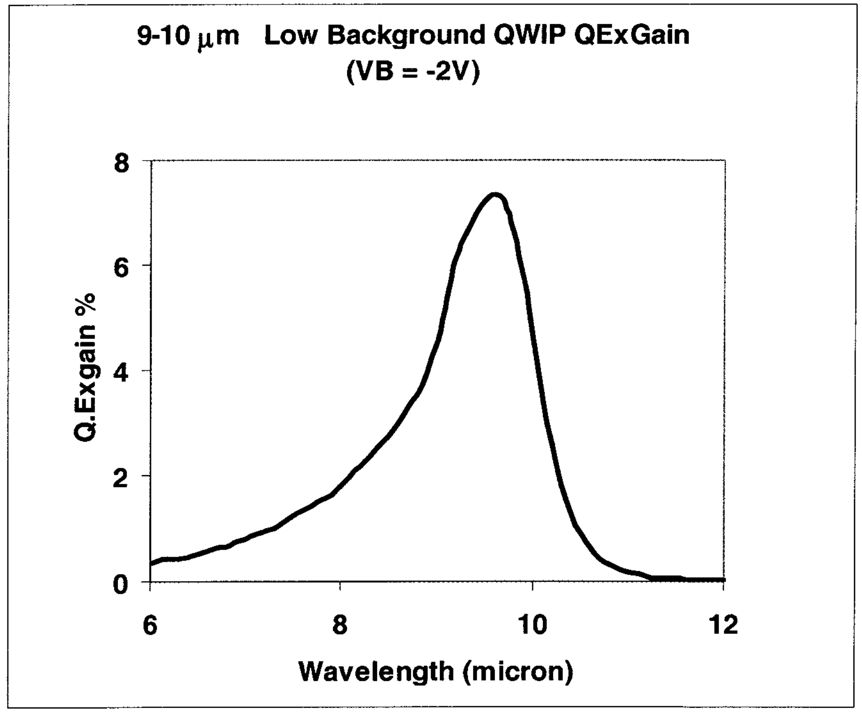
9-10 μm QWIP for Low Background Applications
Photon Flux = 1.5×10^{13} ph/sec/cm^2 (120K, f/2)





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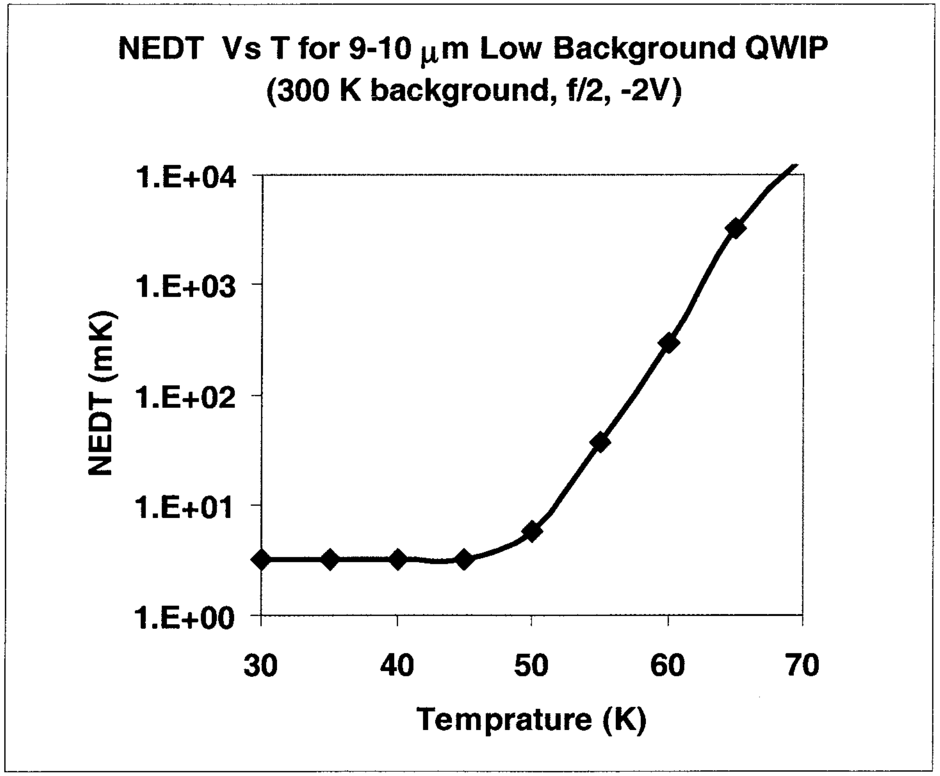

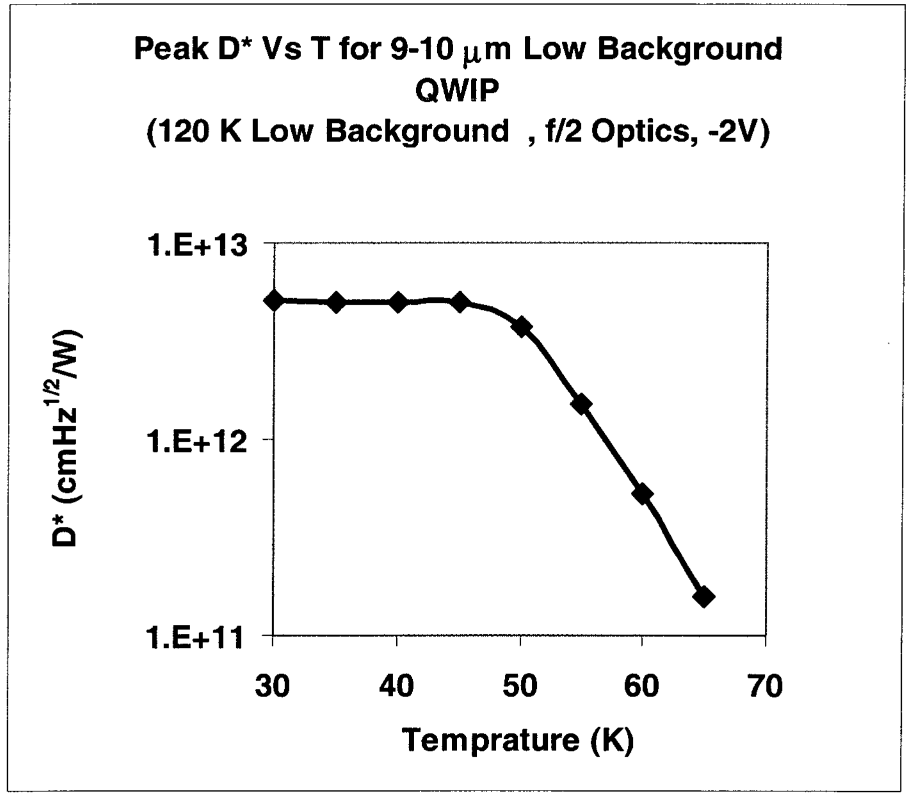

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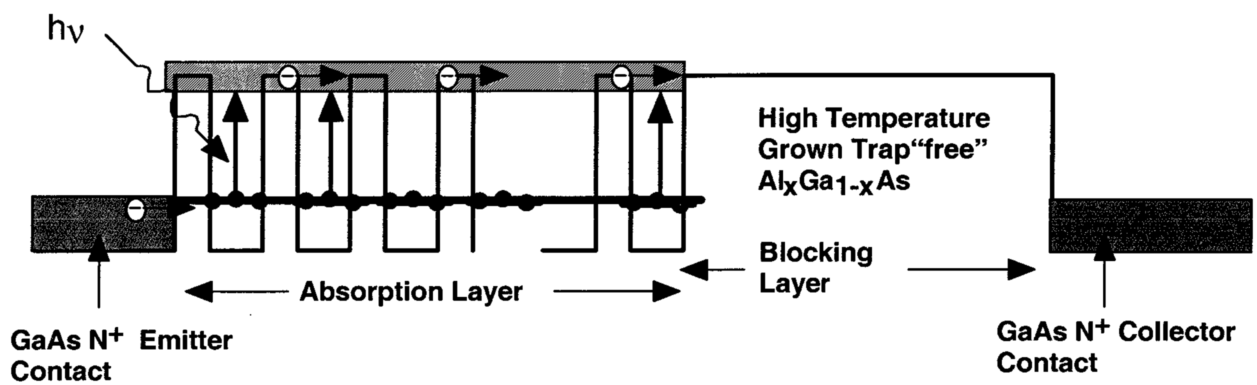
Non-Linear Response of typical QWIPs at Low background

- At low background and low operating temperatures, QWIP responsivity is limited at high optical modulation frequencies:
  - QWIP speed of operation is limited by
    - Carrier capture time (re filling)
    - Transient time across the QWIP
- Similar to extrinsic semiconductor detectors

Ershov et al., J. Appl. Phys., **86**, 6442, 1999,

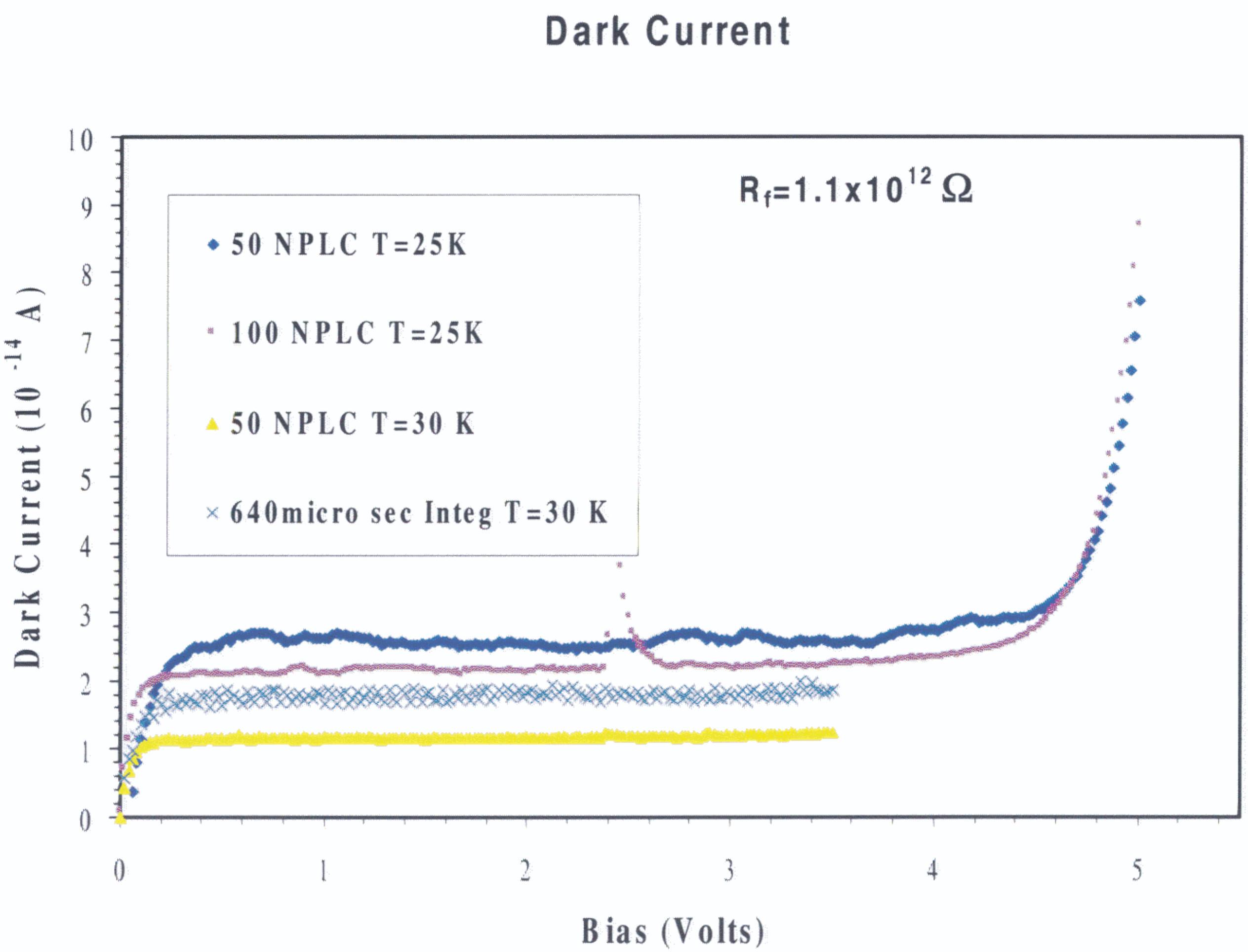
Arrington et al., LWIR Photodetectors & Arrays, Vol VI, ECS 98

Blocked Intersubband Detector (BID)
(for low background, low temperature operation)

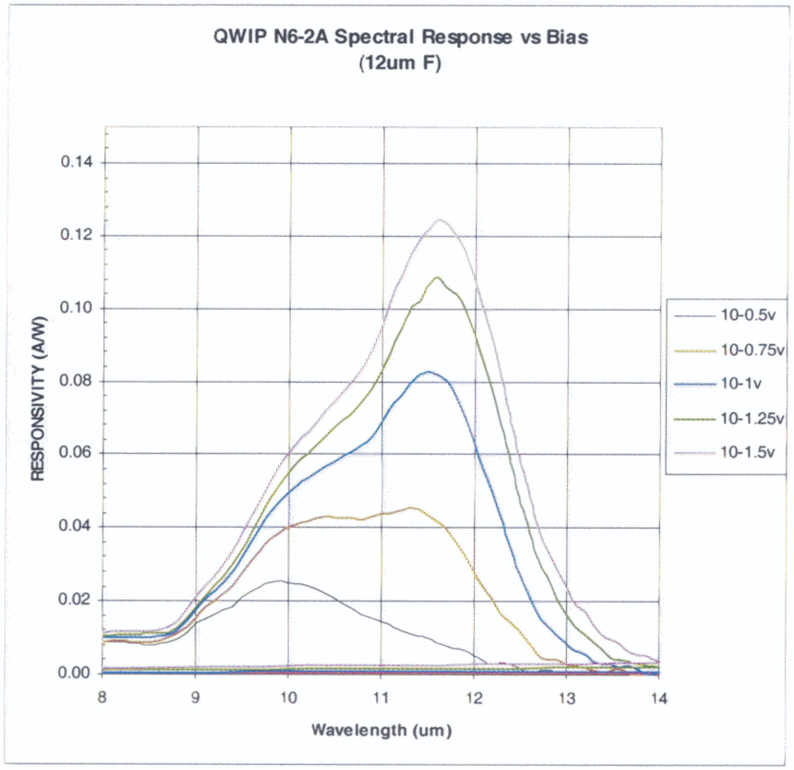


- Thin barriers in absorption layers allow large overlap of sublevel wavefunctions creating a subband.
- Space-charge build up quickly refilled by electrons via tunneling from the contact layer .
- Similar to block impurity band detectors, a thick impurity free blocking barrier is placed between the active region and collector contact to suppress dark current of the device.

BID Dark current at Low Temperatures



BID photo-responsivity measurements



- Absorption measurement goes here

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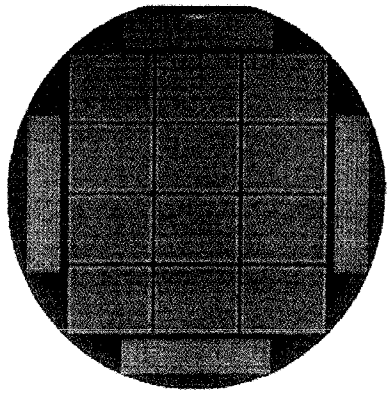
Advantages of BID

- Responsivity wavelength can be tailored to a required wavelength range by changing multi quantum well parameters of the absorption layer
  - LWIR BIDs can operate at 30K
  - allows to use passive cooling for NASA Space astronomy applications
  - Potential candidate for strategic applications
- Broad band Responsivity
- $Al_xGa_{1-x}As$ layer can acts as a reflector allowing light trapping

SUMMARY

- **BIDs - flexible devise design**
  - Tailorable spectral band (Broad and Narrow)
  - Moderate operating temperatures allows Passive cooling in NASA space applications
  - Potential for strategic applications
- **QWIPs - based on high bandgap materials**
  - Matured growth and processing technologies
  - Excellent operability
  - high pixel-to-pixel uniformity
  - Large format FPAs
  - Excellent low frequency noise performance
  - Radiation Hard



Twelve 640x486 QWIP FPA on 3-inch GaAs Wafer